

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2243

EFFECT OF CELL SHAPE ON COMPRESSIVE STRENGTH OF
HEXAGONAL HONEYCOMB STRUCTURES

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SUMMARY

The shape of the cells in a hexagonal honeycomb structure was found, in tests at the Forest Products Laboratory, to be an important factor in determining the compressive strength of the structure parallel to the flutes.

From the results obtained with 35 test specimens of untreated 50-pound kraft paper, a family of curves was obtained by means of which it is possible to estimate the specific compressive strength of such honeycomb structures within the range of the test data. These curves apply only when the cell walls buckle at stresses less than the compressive strength of the material.

The test results indicate that the strength of the cell changes with its shape. It appears from the curves mentioned above that, within the range of the seven shapes studied, for any value of the apparent specific gravity the strength of the structure increases with each increase in cell width, and the strongest cell is that which is widest and has the shortest walls of double thickness. The data indicate that the strongest honeycomb structure for its weight is that for which the hexagonal shape is reduced to a square by shortening the double-thickness walls until they are virtually eliminated.

INTRODUCTION

It has been established that a rather dense material, when formed into a honeycomb structure, has many distinct advantages as a core material for sandwich constructions.

The resistance such a structure offers to flatwise compression and shear of the sandwich is dependent on the stiffness of the honeycomb cell walls. One of the factors that influence the stiffness of the cell walls is the ratio of the dimensions of the various walls and the interaction, or lateral support, they afford each other. Since some of the walls consist of but a single thickness of the base material and the others of two thicknesses glued together, some cell shapes should have greater strength than others.

A series of specimens of hexagonal honeycomb was fabricated and tested. The combined length of all the walls of a cell was the same for all specimens, but the length of the double-thickness walls was increased by increments of $1/16$ inch from $1/4$ to $5/8$ inch. Correspondingly, the length of the single-thickness walls was decreased by $1/16$ -inch increments. The honeycomb structures were made of paper because of ease of manufacture. The general conclusions drawn from the test data apply as well to other materials.

This investigation was conducted at the Forest Products Laboratory under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

PREPARATION OF SPECIMENS

Seven types of hexagonal-honeycomb specimen material were fabricated of untreated 50-pound kraft paper. The combined length of cell walls A, B, C, and D in figure 1 was held constant at $1\frac{1}{2}$ inches, but the cell walls A and C were varied in length by $1/16$ -inch increments (see fig. 2) for each of the seven types of specimens in the desired range of cell shapes to be studied.

For accuracy in the fabrication of the specimen material of the desired cell shape, sheets of paper 12 inches square were laid up and interspaced with strips of phenolic film adhesive. The centers of the strips of adhesive were spaced $1\frac{1}{2}$ inches apart, and successive layers were staggered so that the centers of the strips of any one layer were positioned at the midpoints between the strips of preceding and succeeding layers. Thus the film adhesive strips between alternate sheets of paper were directly over each other. The film-adhesive strips were prepared in widths corresponding to the desired lengths of the double cell walls. This dimension varied from $1/4$ to $5/8$ inch for the seven types of specimen materials. The machine direction of the paper and of the film adhesive was parallel to the direction of the flutes of the honeycomb cells.

The carefully laid-up blanks of paper and film were conditioned at 75-percent relative humidity for 64 hours before being pressed. The bonding was done in a hot press for 15 minutes at 320° F with a pressure of 90 psi. After being bonded, the flat blanks were trimmed to 5-inch lengths in the direction of the flutes on a high-speed circular saw. The blanks were then expanded to form hexagonal cell sections, and specimens of the desired size were cut from the sections with a sharp knife.

After the specimens were weighed and measured, their ends were encased in molding-plaster pedestals to prevent rolling of the edges during the compression tests.

TEST PROCEDURE

The specimens were tested by applying a compressive load parallel to the direction of the flutes and by observing the load at which failure occurred. The tests were conducted in a conditioning room maintained at 75° F and 64-percent relative humidity. The specimens had been conditioned in this room for a period of at least 48 hours before test.

A mechanically driven testing machine was used. The specimens were set vertically with one of the plastered ends down on the flat bed of the machine and the load was applied through a spherical loading head attached to the upper, or movable, head of the machine. Loading was done at a uniform rate of head travel, 0.012 inch per minute, until failure was indicated by the loss of load. The maximum indicated load was recorded.

Complete details of the test method used may be obtained from reference 1.

PRESENTATION OF DATA

Table 1 lists the cell lengths and length ratios for the various cell shapes studied (fig. 1). Column (1) contains the series identification numbers, which are also the lengths of the double-wall portion of the cells in sixteenths of an inch. Column (2) lists the length of the cells and column (3) lists the ratios of the combined length of the cell walls, which in all cases is 1.5 inches, to the length of the cells given in column (2). Column (4) lists the rg values, which are the products of the ratios in column (3) and the specific gravity of the paper, 0.805.

Table 2 lists data showing the effect of the cell shape on the specific compressive strength of the honeycomb. Column (2) lists the value of the maximum compressive load obtained in test of the specimen parallel to the flute direction. In columns (3) and (4) are given the cross-sectional dimensions of the test specimens, while column (5) lists the values of the corresponding apparent compressive strength. In column (6) are given the values of the apparent specific gravity of the honeycomb obtained by dividing its weight in grams at test by the apparent volume in cubic centimeters. Column (7) lists the values of the specific compressive strength of the honeycomb obtained by dividing the values for apparent compressive strength given in column (5) by those for apparent specific gravity given in column (6).

Column (8) lists the values for the constant c from equation (12) of reference 2:

$$c = p_s \left(\frac{rg - g_a}{g_a} \right)^{2/3} \quad (1)$$

where

- p_s specific compressive strength; maximum stress divided by specific gravity of core material, psi per gram per cubic centimeter
 $(p_s = p/g = p_a/g_a)$
- p maximum stress, psi
- g specific gravity of core material; 0.805 gram per cubic centimeter
- p_a apparent compressive strength, psi per gram per cubic centimeter
 $(p_s g_a)$
- g_a apparent specific gravity of honeycomb, grams per cubic centimeter
- r ratio of length of material to length of cell $(r = a_o/a_f = 1.5/a_f)$
- a_o length of material before expansion (see fig. 1); 1.5 inches
- a_f length of cell (see fig. 1), inches

Figure 1 is a sketch of the honeycomb core construction and figure 2 shows a family of curves denoting the relationship of the apparent compressive strength of the honeycomb cores of various cell sizes to their apparent specific gravity.

ANALYSIS OF RESULTS

The average values of the apparent compressive strength of each group of test specimens are plotted in figure 2 as a function of the apparent specific gravity of the particular honeycomb structure. These test averages are shown by the point symbols. By substituting the average test values for c and r of each series in equation (1), and by varying the value of g_a from 0.01 to 0.08 by varying the thickness of the cell walls, the test data were expanded into a family of curves by means of which the compressive strength of honeycomb structures, within this range and that of the data, can be estimated.

Each cell, regardless of shape, was built to contain the same amount of material and therefore had the same weight. From figure 2 it is apparent that for any value of the apparent specific gravity g_a the strength of the structure increases with each increase in cell width, and the strongest cell is that which is widest and has the shortest walls of double thickness. The data indicate that the strongest honeycomb structure for its weight is probably that for which the hexagonal shape is reduced to a square by shortening the double-thickness walls until they are virtually eliminated.

The curves of figure 2 apply only when the cell walls buckle at stresses less than the compressive strength of the material. If the cell walls are made sufficiently thick so that they will fail in compression without buckling, the apparent compressive strength of the honeycomb will be directly proportional to the apparent specific gravity.

Forest Products Laboratory
Madison, Wis., January 5, 1950

REFERENCES

1. Anon: Methods of Test for Determining Strength Properties of Core Material for Sandwich Construction at Normal Temperatures. Rep. No. 1555, Forest Products Lab., U. S. Dept. Agric., revised Oct. 1948.
2. Norris, Charles B.: An Analysis of the Compressive Strength of Honeycomb Cores for Sandwich Constructions. NACA TN 1251, 1947.

TABLE 1.- CELL LENGTHS AND LENGTH RATIOS FOR
HEXAGONAL HONEYCOMB CORES

(1)	(2)	(3)	(4)
Specimen	Length of cell, a_f (in.)	Ratio of length of material to length of cell, $r = \frac{a_o}{a_f}$	Product of specific gravity of core material and r , rg
4	0.793	1.892	1.524
5	.881	1.703	1.381
6	.970	1.546	1.245
7	1.058	1.418	1.142
8	1.146	1.309	1.053
9	1.235	1.215	.978
10	1.323	1.134	.912



TABLE 2.- EFFECT OF CELL SHAPE ON COMPRESSIVE STRENGTH OF
PAPER HONEYCOMB CORES WITH CELLS OF HEXAGONAL SHAPE

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Specimen	Maximum load (lb)	Width of specimen (in.)	Depth of specimen (in.)	Apparent compressive strength, p_a (psi)	Apparent specific gravity, g_a (gram/cm ³)	Specific compressive strength, p_g (psi/gram/cm ³) (a)	Constant, c (b)
4-1	180	3.35	3.05	17.67	0.0172	1024	20,183
2	180	3.35	3.15	17.05	.0166	1027	20,760
3	148	3.40	2.45	17.76	.0192	924	16,928
4	175	3.60	2.85	17.05	.0172	992	19,552
5	209	3.40	3.15	19.51	.0176	1109	21,559
				^c 17.79	^c .0176	^c 1015	^c 19,800
5-1	201	3.30	2.55	23.89	0.0220	1085	16,872
2	179	3.50	2.50	20.46	.0208	984	15,892
3	181	3.30	2.30	23.84	.0235	1015	15,083
4	192	3.35	2.50	22.92	.0220	1042	16,203
5	188	3.35	2.20	25.50	.0248	1028	14,742
				^c 23.32	^c .0226	^c 1031	^c 15,760
6-1	172	3.30	1.65	31.60	0.0318	994	11,272
2	287	3.48	2.35	35.10	.0334	1051	11,508
3	202	3.40	2.25	26.40	.0265	996	12,789
4	255	3.40	2.75	27.28	.0257	1062	13,912
5	258	3.20	3.15	25.60	.0230	1113	15,716
				^c 29.19	^c .0280	^c 1043	^c 13,040
7-1	170	2.50	2.45	27.74	0.0291	954	10,818
2	210	3.20	2.35	27.92	.0280	998	11,627
3	183	3.00	3.05	20.00	.0234	855	11,260
4	170	2.50	2.60	26.16	.0270	969	11,580
5	195	3.25	2.15	27.90	.0287	972	11,391
				^c 25.94	^c .0272	^c 950	^c 11,340
8-1	230	2.70	2.10	40.59	0.0366	1109	10,181
2	275	2.80	2.05	47.91	.0425	1127	9,320
3	258	2.75	1.85	50.75	.0445	1141	9,105
4	327	2.80	2.70	43.26	.0353	1226	11,512
5	280	2.72	2.12	48.60	.0422	1152	9,585
				^c 46.22	^c .0402	^c 1151	^c 9,940
9-1	284	2.55	2.40	46.41	0.0396	1224	10,098
2	415	3.30	2.50	50.35	.0417	1207	9,620
3	243	2.45	1.75	56.65	.0490	1157	8,238
4	307	2.40	2.20	58.15	.0477	1219	8,826
5	365	2.35	2.70	57.55	.0464	1240	9,164
				^c 54.22	^c .0449	^c 1209	^c 9,190
10-1	518	2.50	2.50	82.90	0.0648	1279	7,111
2	552	2.70	2.50	81.80	.0661	1238	6,772
3	510	2.50	2.45	83.25	.0630	1322	7,496
4	540	2.50	2.45	88.20	.0638	1383	7,772
5	532	2.45	2.70	80.40	.0598	1345	7,882
				^c 83.31	^c .0635	^c 1313	^c 7,410

^aApparent compressive stress divided by apparent specific gravity.

^bComputed from equation (1) (equation (12) of reference 2).

^cAverage of five values just above.



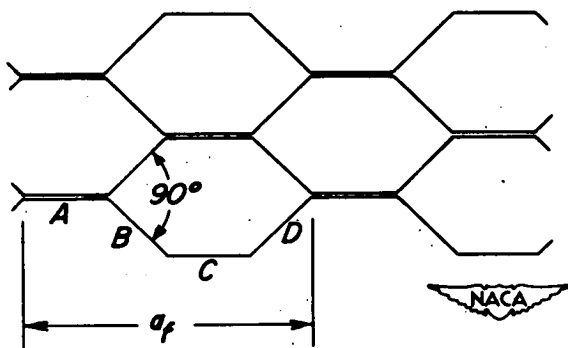


Figure 1.- Sketch of hexagonal honeycomb construction. Sum of lengths A, B, C, and D is 1.5 inches or a_0 ; $A = C$, $B = D$.

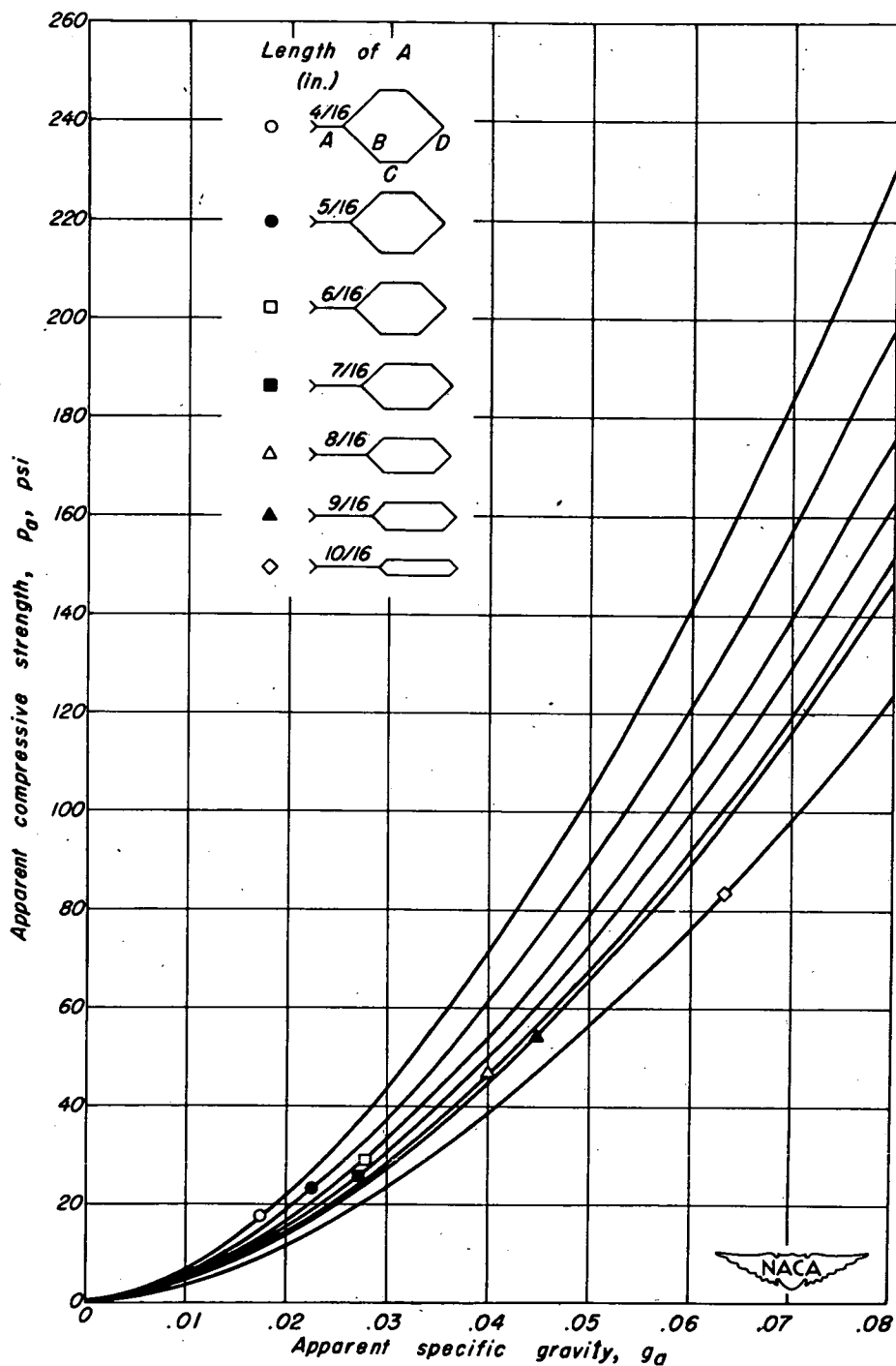


Figure 2.- Apparent compressive strength of hexagonal honeycomb cores tested parallel to flute direction plotted against apparent specific gravity of test specimens. Average test values for different core shapes are shown by point symbols; curves were obtained by substitution in equation (1).